A New Machine for Forest Fire Control:

The Model II Michigan Sand Caster

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Summary

The Model II Michigan Sand Caster is a new type of machine designed to cast a large volume of sand at high velocity for fire suppression. Model II can cast as much as 4 cubic yards per minute from a trench it digs in the ground over which it is towed.

Trials were conducted in Michigan, Georgia, and Florida primarily to evaluate the principle of sand casting in fire suppression, but also to evaluate the machine itself.

Results showed that sand cast in sufficient quantity is capable of extinguishing flames. Used to pretreat fuels, it increases their resistance to ignition and reduces both fire intensity and rate of spread.

The Model II Michigan Sand Caster is a pilot model and should point the way towards a more dependable machine. It operated successfully in open areas with little debris or dense vegetation. However, as the amount of debris and vegetation increased, breaking of shock load shearpins, clogging, and maneuvering proved troublesome. As a result, operations close to the front of an intense fire became risky. Effective direct attack on flames with this machine must be made from 50 feet or less. Although direct ground attacks with other equipment must be made even closer to the fire front, distance still limits the kind and number of fires on which direct sand-cast attacks can safely be made.

Pretreating fuels with a sand cover for indirect fire control was generally quite successful and may offer the greatest promise for the use of this model. Sand casting may also be beneficial in bringing some crown fires to the ground, in corralling the flanks of wildfires, and for work on the rear of fires that require much mop-up.

This machine appeared to perform better in Michigan than in the more complex fuels of Georgia. For effective use in most fuels when only one cast was made the full capacity of the machine was needed; in the more complex fuels even a full-capacity single cast was often inadequate for complete control.

Further development of sand-casting machinery and the development of operational techniques seem justified because of the effectiveness of cast sand in these trials and the abundance of "castable" soil in many areas.

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Soil has long been used in forest fire suppression. Its usefulness in direct attack on flames has been limited by the small amount of soil that can be handled and the short distance it can be spread by a man with a shovel. But it is used on almost all fires in its inactive role of barrier prepared by handtools, fireplows, and bulldozers, and in mop-up work. Successful casting of large quantities of soil might expand its use and provide new techniques for fire suppression.

Sandy soils appear most promising for this technique. These soils are abundant in many forested regions. Unlike water or chemicals, soil is a material that does not have to be transported. But it is heavy and often firmly held in place by roots and plant debris. A great deal of force must be applied to drive sand from its resting place and spread it at high velocity. A completely new type of machine is required to do the job.

Such a machine has been under consideration for many years at the State of Michigan Forest Fire Experiment Station, Roscommon, Michigan. Many types of existing earthmoving and handling equipment were studied and subjected to trial, but none appeared useful for fire control. Several new machines were designed and a few were built to try out mechanical principles. The latest machines, Model I and especially Model II, were the first that appeared to be practical.

The Model II Michigan Sand Caster, an experimental prototype designed for the rapid application of large quantities of sand, was built in 1960 at the Michigan Station under a cooperative agreement with the U.S. Forest Service. Its design

combined the principles and mechanical movements believed necessary in such a machine. By the summer of 1960 the machine was ready for evaluation, and during the fall of 1960 and spring of 1961 trials were carried out in Michigan, Georgia, and Florida.

The two objectives of the trials were to evaluate the principle of sand casting in fire suppression and to evaluate performance of the Model II Caster. The U.S. Forest Service and the states of Michigan, Georgia, and Florida cooperated to carry out the program. Forest Service units participating included the Central States and Lake States Forest Experiment Stations, the Southeastern Station's Southern Forest Fire Laboratory, and Regions 8 and 9.

The evaluation of the principle of sand casting was the primary objective. But the machine itself embodies such unique features that it and its operating characteristics are described to help the reader better understand the results of the trials on fires.

FIGURE 1.— Model II Michigan Sand Caster attached to towing tractor. Rotor has been lowered part way into soil.

The Machine and Its Operation

DESCRIPTION

The Model II Michigan Sand Caster is a towed machine approximately 12 feet long, 8 feet high, and 6 feet wide. It weighs about 7,000 pounds (fig. 1). Mounted on two rubber-tired wheels and powered by a 130-horsepower Ford industrial engine, the machine operates independently, except for the power for its forward movement that can be supplied by a variety of tractors. A crawler tractor of 35 to 40 drawbar horsepower is preferred, as it provides good stability and ample towing power. The machine can also be towed on the highway at 40 to 50 m.p.h. by a ¾-ton pickup. The wheels can be moved forward or backward to shift the center of gravity. This provides ease and safety in hookup, good balance in roading, and rotor clearance in operation.

Sand is propelled by a heavy cutting head or rotor 3 feet in diameter and 9 inches thick, containing six cutting vanes. The rotor spins at about 675 r.p.m. in a vertical plane and can be lowered to penetrate a maximum of about 6 inches into the soil. As the machine is towed forward, a stream of earth is cast out to one side, leaving a rounded trench 25 to 28 inches wide when cutting a 6-inch depth. Rotation is reversible and both depth of cut and direction of the cast can be controlled.

The cutting vanes or blades in the rotor are mounted on pivots permitting a ⅜-inch bite into the soil face. The blades automatically shift pitch when the direction of rotation is reversed. The gear train and motor are protected from sudden stopping of the rotor by a shock load shearpin located just back of the engine. Shearpins can usually be replaced quickly and easily without the operator leaving his seat.

In normal position the rotor plane is perpendicular to the line of travel, but the rotor can be pivoted or "fanned" through 90 degrees, permitting sand to be cast 45 degrees ahead or back of the normal position.

A deflector on either side just above the outer edge of the rotor controls the elevation of the stream of cast sand. When the deflector is fully raised, the unobstructed cast is distributed over a strip 50 to 100 feet wide; with the deflector in the down position, cast sand can be confined to a strip 10 to 20 feet wide.

Hydraulic control of depth of cut, angle and height of cast, and wheel position is provided by use of five valves and six cylinders. A foot clutch to engage the rotor, a shift lever to change direction of rotation, and a throttle complete the controls used by the operator.

Rolling steel flotation wheels 7.5 inches wide and 12 inches in diameter and a floating drawbar permit some control of pitching on irregular ground. Approximately 1,000 pounds of force act on the steel wheels.

Two operators are required; one for the tractor, the other for the caster. An electric horn serves as a signalling device between the operators. Operators of both machines, although protected by wire-mesh guards, should wear hard hats, goggles, and coveralls.

CAPACITY AND PERFORMANCE

The capacity of the Model II Caster is given in cubic yards of sand cast per minute or per 100 feet. Water content of the sand can also be computed, either as gallons per minute or as gallons per 100 feet. (Capacity formulae and computing charts are shown in the Appendix, page 29 and figures 1A and 2A.)

The efficiency of the machine is indicated by sand output per minute, but the sand reaching fuels is best shown by the quantity delivered per 100 feet of travel. Depth of cut and forward speed both influence the sand output per minute; depth of cut alone influences delivery per 100 feet.

Because the trench bottom is round, volume of sand cast decreases rapidly as the cut becomes more shallow:

Depth of cut	Sand cast as percent of volume of a 6-inch deep trench
Inches	*Percent*
2	20
3	36
4	55
5	77
6	100
7	126

Depth of cut in most trials averaged 5 inches or deeper. In soft sand in Michigan a few trenches as deep as 7 inches were cut.

The formula does not apply precisely when the rotor is pivoted away from its normal position (perpendicular to direction of travel). So the actual volume cast may be less but usually will be greater than formula value, depending upon the angle of pivot and the unevenness of the surface. Because the position of the rotor is changed frequently in use and the surface is seldom flat it is impractical to try to compute volumes more precisely than by formula.

Five percent or less of the sand of a trench cut deeper than 4½ inches failed to discharge with the directed flow. Instead, it was carried around by the rotor and deposited on the opposite side (fig. 2). This loss would vary with diameter of the rotor, speed of rotation, depth of cut, and degree of deflection. However, because the material carried over is the topmost soil, flammable litter, and humus, it may be an advantage to keep it away from the fire.

FIGURE 2.—A well-made sand caster line in Georgia wiregrass. Note round-bottomed trench and small amount of sand carried over by rotor (left edge of trench). Soil was cast to right.

Speed of travel in 20 southern trials average 96 feet per minute; in 25 Michigan trials it averaged 86 feet per minute (table 1). Speed varied from only 57 feet per minute in one jack pine slash trial in Michigan to a maximum of 136 feet per minute in wiregrass in Georgia. Assuming a cut 6 inches deep, these extremes represent about 1.3 to 3.9 cubic yards per minute. An output of 4 cubic yards per minute is almost maximum capacity and requires cutting to a depth of 6 inches at a speed of 139 feet per minute (1.58 m.p.h.).

In contrast, plow speeds varied from 151 to 265 feet per minute in Georgia and 80 to 230 feet per minute in Michigan. The highly developed tractor plows can be operated faster than the Model II Sand Caster. But this comparison of sand-caster and tractor-plow speeds can be misleading, because the functions of the machines differ. Nevertheless, an increase in operating speed of the Model II Caster without loss in sand-casting capacity would be desirable.

In Florida where the moisture of the sand was about 2 percent of dry weight, about 16 gallons of water were cast per minute; in sand of 25 percent moisture in Michigan about 160 gallons per minute were cast.[1] These rates of water delivery equal or exceed those achieved by most pumps now used in fighting forest fires.

SAND DISPERSAL

Sand dispersal was measured in an open grass field in Georgia for the four conditions provided by casting against the wind in three deflector positions and casting with the wind in one position. Depth cut was 6 inches. Plastic cups were set at 5-foot intervals on a 100-foot line that was perpendicular to the direction of machine travel (fig. 3). The catch of sand in each cup was weighed and converted to a percent of the total weight of sand in all the cups in a line. One line of cups constituted a replication, and each of the four conditions of dispersal was replicated four times.

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[1]Allowance made for organic matter in this high-moisture soil.

TABLE 1. — SAND-CASTER AND TRACTOR-PLOW RATES IN BUILDING CONTROL LINES

Location and fuel type	Sand caster: Trials	Sand caster: Length of line	Sand caster: Rate of Construction	Sand caster: Forced stops	Tractor plow: Trials	Tractor plow: Length of line	Tractor plow: Rate of Construction	Tractor plow: Forced stops
	Number	Feet	Feet per minute	Number	Number	Feet	Feet per minute	Number
Georgia								
Wiregrass	4	800	123	2	3	600	244	0
Scrub oak/ grass/slash	6	1,200	95	2	3	600	215	0
Palmetto/ gallberry	5	1,000	81	5	4	800	194	0
Florida								
Grass/sand pine/ longleaf scrub oak	4	800	91	1	0	--	--	--
Sand pine	1	200	91	0	0	--	--	--
Michigan								
Oak leaf/grass	9	1,475	88	0	2	260	155	0
Low brush	3	375	86	0	1	120	110	0
Jack pine slash	13	1,852	85	2	2	255	113	0
Mixed oak, jack pine, aspen poles moderate density (cross country)	2	4,752	85	6	0	--	--	--

Dispersal was influenced by both deflector position and by wind direction in relation to the cast (fig. 4). Almost 90 percent of the sand cast against the wind fell within 40 feet of the trench when deflectors were set one-half or less of the way down, and within 25 feet of the trench when deflectors were set three-fourths of the way down (fig. 5). Casting with the wind with no deflection, about 90 percent of the sand fell within 50 feet of the trench. These trials were made with winds of 3 to 5 m.p.h.; casting with stronger winds would increase zone width, while casting against stronger winds would reduce it.

Replications differed greatly in sand dispersal, even at the same deflection and wind direction. Only the cumulative mean is recorded in this report and it should be considered as approximate dispersal, rather than an exact measure. The dispersal pattern is further modified when cast soil is intercepted by vegetation.

FIGURE 3 (Above). — Distribution of cast sand was measured using a grid pattern of plastic cups.

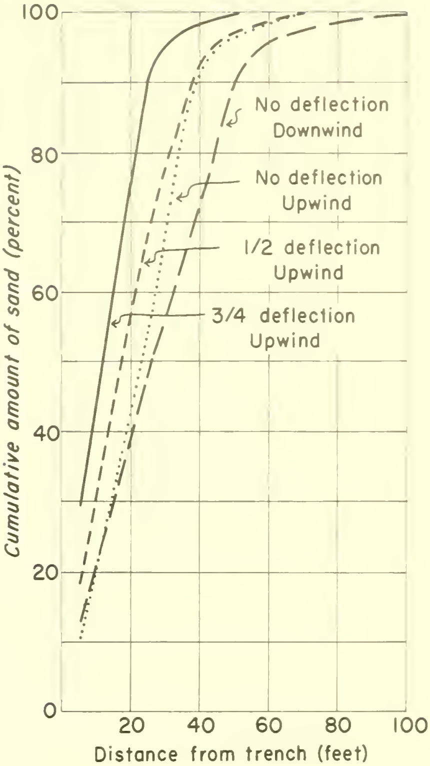


FIGURE 4 (Right). — Sand distribution with different deflection settings and wind directions — Model II Michigan Sand Caster.

FIGURE 5. — Sand was cast up to 100 feet from the trench, but most of it fell within a 50-foot span.

LOST TIME

There were three important causes of lost time in operation: shearing of shock load pins, clogging of the rotor, and lack of maneuvering space.

Shearing of Shock Load Pins

Some method of absorbing the shock of sudden stopping of the rotor is necessary to protect the gears and motor. A shearpin was used in Model II. Breaking the pin caused a loss of time.

In the jack pine slash areas in Michigan, some slash removal was done by hand to clear a path and locate stumps. On 5 of the 6 days of operation in Michigan a small "V" blade was mounted on the front of the towing tractor (fig. 6). Forced stops due to sheared pins were reduced as a result of this measure. Pin shearing was not serious in the low brush, oak leaf/grass, or open jack pine types, but was more frequent in aspen stands.

More difficulty was experienced in the southern trials. Several pins were sheared when the rotor was lowered into the soil too fast or encountered large roots, both in the heavy wiregrass and the scrub oak/grass/logging slash types. But most of the sheared pins occurred in the palmetto/gallberry type and were caused by heavy palmetto clumps.

FIGURE 6.—A small "V" blade mounted on the tractor removed most of the debris ahead of the caster and proved very useful in Michigan.

Clogging

Clogging of the rotor can be caused in several ways. In the palmetto/gallberry type, enough surface debris was sometimes carried along by the steel wheels to lift the rotor out of the ground. In other places, debris and small saplings that became entangled in the rotor axle reduced the speed of rotation or interrupted the flow of sand. Too rapid towing may overwork the rotor. Stalling results if the governor-controlled engine cannot carry the extra load.

Clogging was somewhat less serious in Michigan than in Georgia, probably due to smaller amounts of debris and to the use of the front-mounted "V" blade.

Maneuvering

Both the length of the sand caster (22 or more feet long when coupled with a towing tractor) and its bulk hinder maneuvering among closely spaced trees. Pushed-over trees may also hinder caster operation unless they are moved out of the way. The caster is much less maneuverable than the heavy Mathis plow or the hydraulically controlled Michigan middle-buster-moleboard plow. The disadvantage in maneuverability is less pronounced when the caster is compared with the wheeled Killifer or Wagler plows used in the Lake States. Operator skill, important in either plow or caster operation, may be more critical in caster operation.

Trials showed that the Model II is undependable in heavy going. The amount of time lost due to pin shearing, rotor clogging, and maneuvering difficulties increases with the density of vegetation and amount of surface debris. Moreover, this machine was designed for use in sandy soil and does not perform well in heavy soil or hard sand. Soft or very wet soil probably would not support its weight. Although gravelly soil can be cast, rocky soils in general are not well adapted to casting. They cause excessive wear on parts, and personal injury may result from flying rocks.

Evaluating the Principle of Sand Casting for Fire Suppression

Before trials, it was thought that cast sand might function in two ways in fire suppression. Sand might be applied directly on flames to extinguish them, or it might be used to cover fuels to increase their resistance to ignition, slow or stop the spread of fires, and reduce fire intensity. Cast sand could therefore function both actively and passively. This presumed versatility made it necessary to conduct several kinds of trials. In some instances, the effects of cast sand were compared with those of fireplows and water.

METHODS

Small fires were set in each of seven different fuel areas. Plowlines and burned-out safety strips were established around each plot. In some fuel areas plots 200 feet square were used; in others, 100 or more feet of long strips 100 or 200 feet wide were used.

Although the small fires set for the trials approximate the initial size and behavior of many fires attacked in control work, more complex conditions are encountered on larger wildfires. Trials on wildfires were planned, but opportunities to make them did not occur.

The success of controlling wildfires with cast sand is probably influenced by several things, chiefly:

- Sand
  - Amount
  - Moisture content
  - Temperature
  - Direction of cast in relation to direction of wind and fire spread
- Fuel
  - Kind
  - Moisture content
  - Size and shape
  - Quantity
  - Distribution, arrangement, and density
- Weather (Burning index)
  - Wind
  - Relative humidity
  - Temperature
- Operating conditions
  - Amount of surface debris
  - Soil composition and compaction
  - Amount and size of roots, rocks, and stumps
  - Vegetation
- Use of machine
  - Operator skill—(both tractor and caster operator)
  - Method of using machine
  - Path location and preparation
  - Delays

These factors cover a wide range of conditions that could not be studied in detail. Moreover, unfavorable weather conditions limited the number of replications of trials that could be made in any one fuel type. Similar trials were carried out in

most areas used, however, providing a favorable range of conditions both in weather and in fuel. Observations were made of most of the conditions thought to be of importance and selected measurements are given in the tables of results. Descriptions of fuel areas follow.

FUEL AREAS

Michigan

Oak leaf/grass. — Moderately stocked sapling and pole-sized oak stands with a few larger trees. Fairly uniform oak-leaf and grass fuel cover of about 3 tons per acre.

Low brush. — Sweetfern, blueberry, and associated heath plants with grass and scattered full-crowned jack pine or oak trees. Fine fuels; litter, grass, dead and green low brush, all under 2 inches high, making up about 3 to 5 tons per acre.

Jack pine slash. — One-year-old slash, with red needles still attached, remaining after clear cutting of stands yielding 10 to 20 cords of merchantable pulp per acre. Most slash lay within 3 feet of the ground. Fine fuel; litter, grass, bracken fern, and low brush of 2 to 4 tons per acre; slash of 4 to 6 tons per acre.

Georgia

Heavy wiregrass. — Dense wiregrass, 1 to 2 feet tall, in an open field and difficult to walk through.

Scrub oak/grass/logging slash. — Fairly well-stocked stand of scrub oaks up to 2 inches d.b.h., plus a few larger oaks with dry leaves attached. Scattered longleaf pine logging slash remained from a clear cutting made 2 years before. Wiregrass was the predominant fine fuel.

Palmetto/gallberry. — Five-year-old rough under a twenty-year-old slash pine stand. Fuel density differed from plot to plot but volume averaged 10 tons of available fuel per acre.

Florida

Wiregrass/sand pine/scrub oak.— Light grass fuel with sparse vegetation and litter.

Sand pine. — Sand pine scrub area with young trees very closely spaced and subject to easy crowning. Litter fuels very light.

RESULTS

Direct Application of Sand to Extinguish Flames

Fires started in untreated fuels were allowed to spread downwind; when a fire had gained momentum, its head was attacked with the sand caster. In Michigan, slow-spreading fires in oak leaf/grass and low brush fuels were 90 to 100 percent extinguished with a single cast of sand (table 2). Moisture content of sand in the oak leaf/grass area was about 21 percent; in the low brush type, 7 percent. A single cast of sand extinguished 50 percent of the flame line in Georgia scrub oak type. The remaining flames died as they spread into the sand-cast strip. Three casts of sand containing 10 percent moisture were required to completely extinguish 7- to 10-foot flames slowly spreading in jack pine slash.

A single cast that was dispersed over 75 to 85 feet, however, spread sand too thinly to extinguish flames

Table 2. — Direct application of sand to extinguish flames

Location and fuel type	Sand cast: Casts	Sand cast: Width	Sand cast: Amount	Moisture content: Fine fuel	Moisture content: Soil	Rate of fire spread	Flame height	Spotting ahead	Flame line extinguished	Fire burned to trench	Degree of fire control[1]: 1	2	3
	Number	Feet	Cu. yds. per 100 ft.	Percent	Percent	Feet per minute	Feet	Number	Percent				
Michigan													
Oak leaf/grass	1	30	1.6	6	22	--	2	0	90	Yes	X	--	--
	1	30	1.8	6	22	--	2	0	90	No	X	--	--
	1	30	3.2	7	21	12	3	0	100	Yes	X	--	--
	1	25	2.8	7	21	20	3	0	100	Yes	X	--	--
	1	30	2.8	7	21	--	3	0	100	Yes	X	--	--
Low brush	1	10-30	2.5	10	7	8	2	0	95	Yes	X	--	--
Jack pine slash	1	20	2.3	12	10	6	7	0	60	--	--	--	X
	[2]2	20	4.6	12	10	7	6	0	90	--	--	X	--
	[2]3	20	6.9	12	10	7	3	0	100	Yes	X	--	--
	1	10-40	2.8	12	11	--	12	0	90	--	--	--	X
	[2]2	10-40	5.6	12	11	--	12	0	100	No	X	--	--
Georgia													
Wiregrass	1	75	2.5	6	--	60	15	0	20	Yes	--	--	X
Scrub oak/grass/slash	1	30	2.5	19	7	20	4	0	35	Yes	--	X	--
Florida													
Sand pine/wiregrass	1	40	--	7	2	20	12	0	50	Yes	X	--	--
	[2]2	20	--	7	2	--	--	0	90	Yes	X	--	--
	1	40	2.8	10	5	33	10	0	60	Yes	X	--	--
	1	35	--	6	8	--	8	0	50	--	X	--	--
	[2]2	40	--	6	8	--	5	0	90	No	X	--	--
	1	50	--	6	8	--	--	0	40	Yes	X	--	--
	[2]2	35	--	6	8	--	--	0	90	Yes	X	--	--

1/ (1) Only patrol needed. (2) Patrol, mop-up, and suppression in isolated places needed. (3) Much suppression work needed to control, but fire intensity reduced.

2/ Same test as line above.

FIGURE 7.—Direct attack on intense fires in Georgia's wiregrass fuel was hazardous and often inadequate for complete control.

or to control a fast-spreading fire in heavy Georgia wiregrass (fig. 7). Direct casting on flames in palmetto/gallberry was not attempted because of operating difficulties in that type and because of the danger of having to abandon the machine in front of a fast-moving fire if a pin was sheared. Due to light variable winds, fires did not persist in Florida sand pine crowns. In one instance, sand cast into the flames of a developing crown fire immediately brought it to the ground where it eventually went out.

There is little doubt of the ability of cast sand to extinguish flames, but there are limits to the ability of Model II to cast sufficient sand in a single cast to extinguish intense fires. Moreover, the hotter the fire the closer to the fire the machine must be operated, but as fire intensity increases, the chance of safe operation at close range decreases. Beyond 50 feet the chance to extinguish flames is slight, and direct attack on flames would have to be abandoned in favor of indirect methods. No attempt was made to study various tactics of use or combinations of direct and indirect methods.

Pretreatment of Fuels

Several evaluations of pretreatment were made. Ignition and spread of fires lighted simultaneously in sanded and nontreated strips were compared. Effectiveness of

sand-casting in stopping head fires and as backfire control lines was compared with that of standard plowlines.

Ignition and spread trials were made only in oak leaf/grass fuels and jack pine slash in Michigan. Sand was cast on a strip of fuel on the plot, leaving the remainder untreated. Both short and long casts were tried. Four parallel lines of fire perpendicular to the caster line were then lighted across both treated and untreated fuels. Drip torches used for ignition contained a mixture of fuel oil and gasoline.

Cast sand sharply reduced the number of ignitions and retarded fire spread (figs. 8 and 9). Its effectiveness varied with length of cast and fuel-bed makeup (table 3). In contrast, fires spread rapidly across all of the untreated area. No more than 20 percent of any treated area with one exception, was burned over. The exception was a fire that spread across 80 percent of an oak leaf/grass area treated with a full-length cast (no deflection) 3 hours before ignition. But fire burned only a small amount of the fuel. Less than 1 percent of the treated strip of an adjacent plot burned when a 20-foot cast was allowed to dry for 3 hours. Much of the burned area in treated strips was caused by fire creeping back from the untreated portion of a plot, often in an untreated "shadow" in the lee of a tree.

Because the fine fuels were either covered by sand or separated too much by the sand, few of the fires started in the treated oak leaf fuels spread rapidly, and many of them went out (fig. 10). For the same reasons, fires ignited in the fine fuels in jack pine slash spread slowly. Because the heavier slash is generally ignited by flames from the fine fuels, ignition and spread of fires in the heavier slash was also reduced. Despite the much smaller portion of treated area burned, the burning time was generally longer in treated than in untreated fuels because of the slow spread of the flames. Fuel consumption was also much reduced.

FIGURE 8.—Fires were started by drip torches in lines across untreated (left) and treated (right) portions of plots. Spread was rapid across the untreated portion, but fires did not ignite or spread readily in the treated part.

FIGURE 9. — Drip-torch ignitions in jack pine slash. Fires burned briskly in untreated slash in background; in sand-cast strip in foreground they burned slowly.

FIGURE 10. — Ignition and spread of fire in oak leaf/grass fuels were hindered by sand because it covered fine fuels or separated them from other fuels.

Table 3. — Ignition and spread

Location and fuel type	Treatments		Plot size		Moisture content		Burning time		Estimated portion of plot burned	
	Casts	Width	Treated	Untreated	Fine fuel	Soil	Treated	Untreated	Treated	Untreated
	Number	Feet	Square feet	Square feet	Percent	Percent	Minutes	Minutes	Percent	Percent
Michigan										
Oak leaf/grass	1	20	2,000	7,500	9.0	[1] 16	10.0	10.0	2	100
	1	20	2,000	5,500	6.6	21	1.0	2.0	1	100
	1	50	4,000	7,500	10.0	16	13.0	11.1	5	100
	1	50	4,500	7,500	9.0	16	8.5	8.5	5	100
	1	50	6,500	3,300	7.0	[1] 16	14.0	10.0	20	100
	1	50	5,000	6,000	6.6	21	5.0	2.5	80	100
	2	48	4,500	7,500	10.0	16	7.0	6.8	1	100
	2	45	4,500	10,000	8.0	16	2.0	9.0	1	100
Jack pine slash	1	20	1,800	4,500	11.7	13	15.0	9.0	10	100
	1	20	1,800	4,500	11.7	13	20.0	15.0	10	100

1/ Sand cast 3 hours before burning of plot. High soil moisture due to moisture held in humus. Moisture of soil 2 to 6 inches below surface was 9 to 11 percent.

Head Fires Burning into Sand-Cast Zones

Head fires given about a 100-foot run were allowed to burn unhindered into pretreated sand-cast strips in all fuel types. Three methods were tried including single casts made with and against the wind and a double cast. In the double cast, one cast was made with the wind, the other into the wind about 20 feet apart. In this way a double portion of sand was cast into a common middle strip 20 feet wide bordered on both sides by caster trenches.

Results of casting towards the approaching fire (against the wind) showed that the sand-cast strips stopped fire under trial conditions (table 4). Spreading fires in oak leaf/grass and low brush fuels in Michigan, in scrub oak and wiregrass in Georgia, and in both wiregrass/sand pine and sand pine scrub in Florida were stopped. A fast-moving head fire in the heavy wiregrass type in Georgia licked across a double plowline 15 feet wide (table 5), (fig. 11), but was stopped by a low-deflection sand-cast zone. Most of the 2.8 yards of sand cast per 100 feet dropped within 25 feet of the trench. On reaching the outer edge of the sand-cast zone, the flames began to shorten appreciably and the production of smoke increased greatly. Although flames burned to the trench, their height was reduced from 10 feet to 2 and their rate of advance was more than cut in half.

FIGURE 11. — Neither this single plowed line nor a 15-foot-wide double one stopped a fast-moving wiregrass head fire.

Table 4. — Head fires burning into cast strips

SINGLE CAST TOWARDS FIRE

Fuel type	Sand cast		Moisture content		Rate of fire spread	Flame height	Ignitions downwind from treated strip	Fire stopped by cast strip (spotting excepted)	Fire burned to trench	Spread and intensity reduced
	Width	Amount	Fine fuel	Sand						
	Feet	Cu. yds. per 100 ft.	Percent	Percent	Feet per minute	Feet	Number			
Oak leaf/grass	25	2.5	7	21	--	3	0	Yes	Yes	Yes
Low brush	20	2.5	13	7	9	2	0	Yes	Yes	Yes
Jack pine slash	25	2.8	11	10	--	25	2	Yes	Yes	Yes
Wiregrass	20	2.8	9	--	66	10	0	Yes	Yes	Yes
Scrub oak/grass/slash	25	2.8	7	7	120	12	0	Yes	Yes	Yes
	30	2.2	6	--	20	10	0	Yes	Yes	Yes
Palmetto/gallberry	30	2.5	7	15	38	25	2	Yes	Yes	--
	40	2.5	7	15	16	25	1	Yes	Yes	--
	40	2.5	7	17	17	15	0	Yes	Yes	Yes
	30	2.3	7	15	31	12	2	No[1]	Yes	Yes
Sand pine/wiregrass/ scrub oak	35	2.8	9	7	24	8	0	Yes	Yes	Yes
	40	3.2	6	7	36	6	0	Yes	Yes	Yes
Sand pine[2]	40	2.9	8	2	31	20	0	Yes	No	Yes

SINGLE CAST AWAY FROM FIRE

Oak leaf/grass	25	2.8	7	21	9	4	0	Yes	Yes	--
Low brush	20	2.5	13	7	--	5	0	Yes	Yes	--
Jack pine slash	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Jack pine slash 3/	20	5.4	12	10	12	15	1	Yes	Yes	--
	20	5.7	11	10	--	20	2	Yes	Yes	--
Scrub oak/grass/slash 4/	30	5.6	7	7	81	10	0	Yes	Yes	--
Wiregrass	20	5.0	6	—	6	6	0	Yes	Yes	--

1/ Fire jumped where palmetto clump caused rotor to rise, resulting in shallow cut.
2/ Poor test fire.
3/ Two spots ignited in the treated strip in each of these two trials but all four went out without crew action.
4/ Three spots ignited in the treated strip in this trial but were extinguished.

Table 5. — Fires burning into plowline

Fuel area	Plowline		Moisture content		Rate of fire spread	Flame height	Spots between plowline	Spots down-wind of plowline	Fire stopped by plowline (spotting excepted)	Fire burned to plowline
	Number	Width	Fine fuel	Sand						
		Feet	Percent	Percent	Feet per minute	Feet	Number	Number		
Oak leaf/grass	1	5	7.0	25	9	2	--	0	Yes	Yes
	1	5	7.0	25	3	3	--	4	No	Yes
Jack pine slash	2	1/ 5	12.0	13	8	12	3	1	No	Yes
	2	1/ 5	7.0	21	8	12	1	0	Yes	Yes
Wiregrass	1	6	7.0	--	50	10	--	1	No	Yes
	2	15	11.2	7	120	15	--	3	No	Yes
Scrub oak/grass/slash	1	7	11.2	7	85	10	--	2	No	Yes
	2	15	11.2	7	65	8	7	0	Yes	Yes
Palmetto/gallberry	2	16	6.6	16	16	20	1	0	Yes	Yes
	2	20	5.1	17	18	15	0	2	No	Yes
Sand pine/wiregrass	2/ 1	--	9.4	7	15	3	--	2/ 0	Yes	Yes

1/ Two lines 10 feet apart.
2/ Fire spread too slowly for good trial.

Similar results were obtained in a fire in jack pine slash in Michigan. The flame height and rate of spread were both greatly reduced in the sand-cast zone, though the fire burned through to the trench. A spot fire started beyond the control line. It was not suppressed but could easily have been controlled because of the reduced intensity of the head fire.

Only one of the three fires burning into a plowed break in the palmetto/gallberry type was a good head fire. In this instance, the fire jumped the two plowlines. The 25-foot-sand-cast strip proved very effective in stopping fire in this type, especially where the palmetto was not tall and thick. Although the machine generally did not perform well in heavy palmetto clumps, the strips on which it cast full volumes of sand effectively retarded fire spread (fig. 12).

The effect of cast sand on the movement of crown fires was observed in dense, young jack pine. In an area of scattered pine and low brush fuel, a light spray of water followed by a casting of sand was given the downwind side of two dense jack pine sapling thickets, each about 0.2 acres in size. Part of the sand stuck in the crowns; part filtered down on the ground fuel. Due to excellent burning conditions, head fires set about 100 feet upwind reached the pine thickets with high intensity. Although a few exterior tree crowns caught fire, the flames failed to travel in the crowns, even those not treated, and the ground fire went out completely at the edge of the cast sand under the tree crowns.

Casting away from the spreading fire (with the wind) was tried only in Michigan. Low-intensity fires in

FIGURE 12. — Although the Model II Sand Caster had difficulty traversing the extremely hazardous palmetto/gallberry fuel in south Georgia, the sand-casting principle shows promise in controlling fires in this type.

low brush and in oak leaf/grass were easily stopped. A more demanding trial, however, was made in jack pine slash using a high-intensity head fire. Fire with flames 10 feet wide and 20 feet high did not cross the trench. Furthermore, falling embers did not ignite the 20- to 30-foot strip of sand-covered slash on the other side (fig. 13). Within 30 minutes a less intense fire, also in jack pine slash, easily spread across two plow furrows 10 feet apart (fig. 14).

A dead and down oak retaining most of its leaves lay in a sand-cast strip in one trial in oak leaf/grass fuel. Similar dead trees that lay in untreated areas had burned well. But the leaves of the treated tree

FIGURE 13. — (A) Head fire was set to burn into sand-cast strip. Sand was cast away from the fire — with the wind.

(B) Many burning embers fell into the treated jack pine slash on the right, but no ignitions occurred.

FIGURE 14.—A less intense head fire than that shown in figure 13(A) spread across two plow furrows about 10 feet apart.

failed to burn, even when given a generous dousing of flaming oil from a drip torch after the trial was completed.

Double-casting from both sides of a common strip 20 feet wide with twice the amount of sand as a single-cast strip afforded excellent fuel fireproofing. Trials were carried out in jack pine slash in Michigan and in heavy wiregrass and scrub oak/logging slash in Georgia. In the jack pine slash many embers were seen falling in the 20-foot strip treated with about 5.5 cubic yards of sand per 100 feet. But none burned more than an 18-inch-diameter circle before going out (table 4).

Backfiring from Sand-Cast Zones

Backfiring is hazardous, even when done by skillful and experienced firefighters. It is not always successful and is avoided by some organizations because of the risk. The conditions under which backfiring may be attempted vary widely, and the trials involving backfiring were not made under the most trying circumstances. They serve mostly as indicators.

Two periods are critical during backfiring. The first occurs when the backfire is started. At this point embers or flames may blow across the control line and ignite fuel outside. These breakovers must be controlled immediately or a new head fire is started. The second critical period occurs when the backfire and head fire burn together. The increased heat where the two fires meet nearly always produces strong convection in which a large number of burning embers rise. Many well-conceived backfires have proven futile at this stage because embers were carried past the control line.

In the early stages, every additional foot in depth of the non-flammable zone that separates the backfire from the area to be saved

increases the margin of success. In the second critical period, widening the burned-out strip between the control line and the meeting of the backfires and head fires increases the chance of success.

If enough sand can be cast on the fuels, a sand-cast strip 20 feet wide has much merit as a safety zone from which to carry on backfiring (table 6). Four trials were made in the scrub oak/grass/logging slash in Georgia. Two trials of backfiring were made from a single plowline. In both cases the burned-out strip was 12 feet wide before the head fire and backfire met. In one trial, this treatment successfully stopped the fire; in the other, three spot fires occurred when the backfires and head fires met and scattered a shower of sparks downwind from the plowline. Backfiring from the edge of a sanded strip cast towards the head fire or from the trench of a cast made away from the fire, however, created isolation strips of 30 to 40 feet in a short time and effectively stopped the spread of the head fires.

In heavy wiregrass results were inconclusive or control was unsuccessful. By error the cast on one plot was made from a trench 3 inches deep instead of the usual 6 inches. The backfire burned through the cast strip, crossed the trench, and burned to the end of the plot. Spotovers from a very intense, fast-moving head fire accounted for the other failure.

Results of backfiring in jack pine slash were compared for casting against the wind, with the wind, and to a common zone from two lines 20 feet apart. Backfiring from the irregular edge of a treated zone cast against the wind was successful. As in the Georgia scrub oak fuel, the backfire burned through to the trench at a slow rate, additionally fireproofing the sand-cast zone.

Lighting the backfire at the trench of a strip cast with the wind and letting it burn back toward a head fire over a nontreated area also resulted in an effective barrier. No spot fires started in the treated strip and none occurred downwind from it (fig. 15).

FIGURE 15.—Backfire in jack pine slash burning back from sand-cast strip (right), in light wind. Note shape of trench made when rotor was swung forward and back to fan the flow of sand. Fanning in this way improves the coverage of sand on fuels. There were no spot fires in the treated strip.

TABLE 6. — BACKFIRING FROM SAND-CAST STRIPS

Fuel type	Sand cast: Casts	Sand cast: Width	Sand cast: Amount	Moisture content: Fine fuel	Moisture content: Sand	Backfire: Rate of spread	Backfire: Flame height	Ignition spots in treated strip	Ignition spots downwind of treated strip	Backfire held by cast strip	Backfire burned to trench
	Number	Feet	Cu. yds. per 100 ft.	Percent	Percent	Feet per minute	Feet	Number	Number		
SAND CAST AGAINST WIND											
Oak leaf/grass	1	20	2.8	7.0	25	--	4	--	0	Yes	No
Jack pine slash	1	20	2.2	12.0	10	--	5	--	0	Yes	Yes
	1	20	2.5	12.0	13	--	4	--	0	Yes	Yes
Wiregrass	1	25	1.6	8.0	--	10	8	--	1	No	Yes[1/]
Scrub oak/grass/slash	1	25	2.3	7.0	--	6	4	--	0	Yes	Yes
Palmetto/gallberry	1	35	2.2	5.1	17	--	--	--	0	Yes	Yes
Sand pine/wiregrass	1	40	3.6	6.1	7	3	--	--	0	Yes	Yes
SAND CAST WITH WIND											
Oak leaf/grass	[2/] 1	20	2.8	--	--	5	2	0	0	Yes	No
Jack pine slash	1	20	2.6	11.5	10	3	9	0	0	Yes	--
	1	20	2.2	12.0	13	5	8	0	0	Yes	--
Wiregrass	1	20	3.0	6.2	--	2	4	1	0	No	--
Scrub oak/grass/slash	[2/] 1	25	2.5	7.0	7	3	3	0	0	Yes	--
SAND CAST TO COMMON 20-FOOT STRIP											
Jack pine slash	2	20	5.0	11.0	10	4	22	0	5	No[3/]	--

1/ Sand caster rotor set too shallow in ground.
2/ Fire became a flank fire and trial was poor.
3/ Sand cast strip was safe. Fire spotted downwind from strip and was put out by sand caster.

A more intense fire occurred for the trial in the double-cast strip. Five fires spotted downwind from the strip, but none within it. The spot fires spread rapidly and because of the failure of a pumper unit, the sand caster was called into action. The small fires were easily controlled by a direct cast of sand on the flames.

DISCUSSION

Direct Application

Sand probably extinguishes flames by cooling hot fuels below their ignition temperatures, by smothering burning fuels with a covering that excludes oxygen, or by mechanical action that separates the burning fuel particles from unburned fuels. All three processes may be accomplished by the same cast of sand.

When the quantity of available fuel is increased, when heat is intensified, or when the burning fuel is so arranged that it is difficult to strike or cover, more sand is needed to extinguish the fire. While it is impossible to prescribe the amount of sand needed for flame suppression in all cases, it is clear that direct attacks on flames with the Model II Sand Caster are limited to low-intensify fires (fig. 16). The amount of sand cast beyond 50 feet decreases very rapidly, and would generally be inadequate to extinguish flames of a fire hot enough to prevent working within 50 feet, as in the fast-spreading Georgia wiregrass fires. But casting from 20 to 50 feet extinguished most of the less intense flames in oak leaf and low brush fuels. More intense fires may be attacked if they are moving slowly and if it is possible to make multiple casts.

FIGURE 16 — Although many head fires are too intense to attack directly, short range attacks by the sand caster on flanking fires were often successful.

The risks of shearing a pin or becoming entangled in vegetation severely limit safe operation in attacking intense fires. Use of the present model ahead of an intense fire in many fuel types would be unsafe. Even operators with more skill and experience than any now possess would still encounter delays at critical times.

It is perhaps significant that few, if any, other ground methods can be used to suppress flames from 20 to 50 feet away. Water must be applied in large volume and high pressure at that distance and is seldom attempted.

Pretreatment

Casting sand on fuels in the path of fires resulted in fewer ignitions, slower fire spread, and reduced fire intensity. These results may be produced in several ways. In most instances, sand is cooler and wetter than the dead fuel, thereby increasing fuel moisture and decreasing fuel temperature. Sand insulates fuel from radiant heat and may also reflect away some of the impinging radiation, thus preventing a rapid rise in temperature when fuel is exposed to flames. Fine fuel particles are separated from each other and from heavier fuels by the cast sand. Because fine fuels are usually ignited first, and in turn ignite the heavier fuels, such isolation may effectively prevent or retard fire spread. Covering sand weights down fuels such as oak leaves that are easily blown by the wind. Even if a portion is ignited, the leaf cannot blow away. Once the uncovered part burns off, effectiveness of the leaf as a brand is largely past (fig. 10). The force of the sand striking loose bark, brittle twigs, dead leaves and needles, tall grass, and other types of material can break off or bend down and cover them, thus isolating more of the fine fuels.

As much as 80 percent of some fuels lying close to the ground was effectively isolated or insulated from the heat sources. The remaining fuels, although flammable, were larger and dispersed more widely so that fire ignition and spread were both greatly hindered. The greater quantity and depth of jack pine slash than of other fuels, for example, resulted in poorer sand coverage and consequently more ignitions. The fine fuel seldom caught on fire, however, so fire spread was still slow.

Sand cast away from an advancing fire tends to cover and stick to the exposed side of the fuels nearest to flames and radiation. Fuel continuity is broken at the clean trench and fire spread is stopped abruptly as long as spot fires do not occur beyond the strip. Even if burning embers fly across the trench, ignition is not likely within the sanded zone.

Sand cast towards the approaching flame front sticks to the side away from the heat, giving less protection to the side of the fuel next to the fire. Although the fire's spread may be greatly reduced, even in slash fuels, it can still burn under the sand-casted fuels and, in most instances, fires burned slowly through to the clean trench. This method was preferred by some, however, because the last barrier of defense is a clean trench and fuels and

firefighters beyond the trench are exposed to a fire of reduced intensity.

Ignition resistance and fire-retarding quality of sand-cast strips were high. The greater width of the cast strips as compared with plowlines is a distinct advantage in holding either head fires or backfires. However, none of the fires were carried along by a strong wind and only one trial utilized very dry sand. Until these conditions have been more completely evaluated, caution in the interpretation of results is necessary.

Sand-cast strips do not control long-distance spotting that sometimes takes place 600 to 1,000 feet or more ahead of the main fire front any better than plowlines. In most instances where two or more casts are possible before a fire strikes, better use can be made of the machine by increasing width of the area cast rather than by repeat casting to increase the safety of a narrow strip. In any case, pretreated strips have their greatest value when the fire has not spotted before reaching their leading edge.

Further development of sand-casting machinery and operational techniques seem amply justified by the abundance of usable soil in many areas and by the effectiveness of cast sand in fire control. Increasing the speed of operation, the capacity of casting, and maneuverability should certainly result in a more dependable machine with wider uses.

Appendix

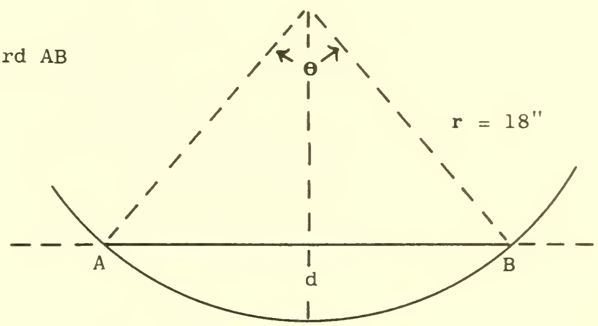
COMPUTING FORMULAE FOR VOLUME OF SAND AND WATER

θ, angle subtended by chord AB

r, radius of rotor

d, depth of cut

AB, width of trench at ground surface



Cross-section area of circle segment of radius 18" (A) in square yards:

$$A = \frac{2.8274\ \theta - (18-d)(\sqrt{d(36-d)}\ )}{1296}, \text{ where } \tan\frac{\theta}{2} = \frac{\sqrt{d(36-d)}}{18-d}$$

Volume of sand in trench (V) in cubic yards:

V = AL, where:

A = Area in square yards and,
L = Length of trench in yards

Width (AB) of trench at ground surface in inches

$$AB = 2\sqrt{d(36-d)}$$

Water content of sand (G) in gallons per cubic yard:

G = 333.24 Sm, where:

Sm is the ratio of weight of water in sand to dry weight of sand, and the following constants are used:
Dry sand = 103 pounds per cubic foot, and
Water = 8.345 pounds per gallon.

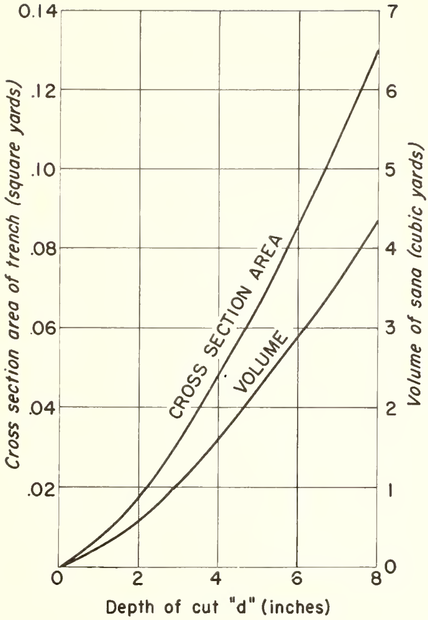


FIGURE 1A. — Cross-section area of trench and volume of sand cast per 100 feet by Model II Michigan Sand Caster at different depths of cut.

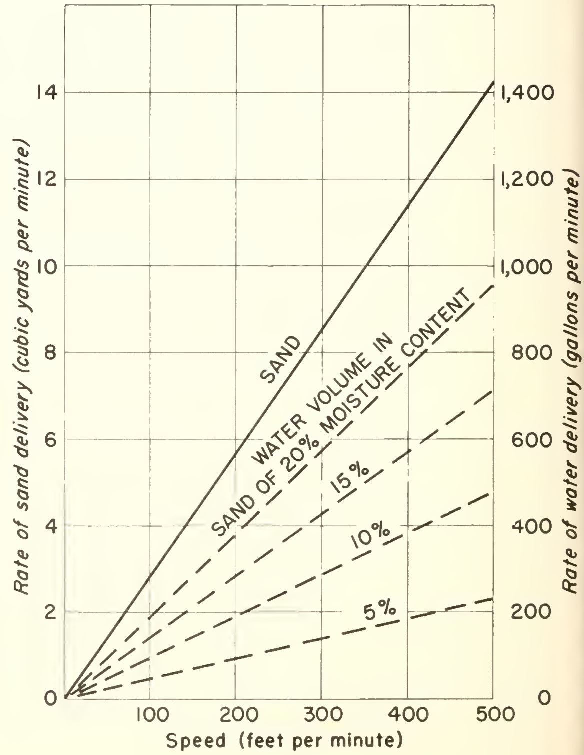


FIGURE 2A. — Rate of delivery of sand and water by the Model II Michigan Sand Caster from a 6-inch deep trench when towed at different speeds.

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